EFFECTS OF ACCELERATED AND OUTDOOR AGEING ON LEACHABILITY AND PROPERTIES OF *COMPREG*-LAMINATED SESENDUK WOOD

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Submitted April 2016; accepted July 2016

This study evaluated the effects of accelerated and outdoor ageing on *compreg*-laminated sesenduk (*Endospermum diadenum*) wood and correlations between these two ageing methods were established. For outdoor ageing, samples were exposed to tropical weather for 1, 3 and 6 months. For accelerated ageing, cyclic boil–dry treatment involving 1, 2, 5 and 10 cycles were employed. Results revealed that density and weight loss were observed after the ageing treatments. After 6 months of outdoor ageing, water absorption of aged phenol formaldehyde and phenol formaldehyde urea-treated samples increased from 3.0 to 13.3% and from 4.1 to 26.6% respectively. Similar behaviour was also observed for samples which underwent 10 cycles of accelerated ageing. Samples subjected to outdoor ageing had thickness swelling higher than that of accelerated ageing (4.3–4.5% vs 2.4–3.7%). Most of the samples lost 8.3 to 22.4% of initial modulus of rupture after 1 month of outdoor ageing. Treated samples retained 61.7 to 77.1% of its initial modulus of elasticity after 10 cycles of accelerated ageing while the untreated samples retained only 48.7%. Emission of formaldehyde decreased with increased exposure times and cyclic boil–dry cycles. As confirmed by Pearson's correlation test, there were good correlations (r = 0.71–0.99) for properties of samples between accelerated ageing and outdoor ageing.

Keywords: Ageing tests, correlation, cyclic boil–dry, *Endospermum diadenum*

INTRODUCTION

Phenolic resin treatments impart better properties to low density tropical hardwood, which is gaining favour owing to the depletion in commercial hardwood (Lee & Zaidon 2015, Nabil et al. 2015, Zaidon et al. 2015a). Unfortunately, poor strength properties and nondurability of the low density tropical hardwood have limited their final applications. On that account, a series of studies using phenolic resin treatments were carried out to improve the mechanical strength, dimensional stability and biological durability of low density tropical hardwoods such as sesenduk (*Endospermum diadenum*), jelutong (*Dyera costulata*), rubberwood (*Hevea brasiliensis*) and mahang (*Macaranga* sp.) (Ang et al. 2014, Zaidon et al. 2015a, b, c).

Compreg-laminated wood is fabricated using wood strips impregnated with phenol formaldehyde (PF) resin followed by compression in laminae form under high temperature using hot press. Nevertheless, the information on the performance of this particular product is very limited due to its novelty. Only a few studies have been conducted on mechanical properties and dimensional stability of *compreg*-laminated sesenduk, jelutong and oil palm wood (Rabi'atol-Adawiah et al. 2012, Aizat et al. 2014, Zaidon et al. 2016). The studies revealed that the performance of the *compreg*-laminated wood was superior to that of solid wood. Unfortunately, work on the leachability of bulking agent from the *compreg*-laminated wood is scarce. In order to promote *compreg* laminates for structural or exterior application, basic information on the leaching caused by ageing should be first established. Leaching will cause weight loss of *compreg* laminates and subsequently reduce their strength. Long-term outdoor exposure test and short-term accelerated ageing test are prevalent methods to evaluate the reaction of wood-based panels towards ageing treatment (Kojima & Suzuki 2011). Both tests are intended to evaluate the performance of wood-based panels under actual environmental conditions. The correlation between accelerated ageing test and outdoor ageing test were once questionable as some earlier works suggested that laboratory treatments were more severe (Baker & Gillespie 1978, River et al. 1981). However, a study conducted by River (1994) revealed strong correlation (Pearson's and Spearman's correlation coefficients > 0.90) between modulus of rupture (MOR) values after accelerated and outdoor ageing. Hence, a cyclic boil–dry treatment modified by River (1994) was used in this study to evaluate the performance of *compreg* laminates made from sesenduk wood. The present study evaluated the durability of *compreg*-laminated sesenduk wood using accelerated ageing (cyclic boil–dry treatment) test and outdoor ageing test. The effects of both tests on the physical and mechanical properties of *compreg*-laminated wood were evaluated. The correlation of properties between these two methods was established. The effectiveness of the phenolic resin treatment on the low density hardwood in comparison with untreated solid sesenduk wood was also assessed.

MATERIALS AND METHODS

Air-dried sesenduk strips, produced from tangent cutting with nominal dimensions of 200 mm long × 25 mm wide × 5 mm thick were used in this study. Low molecular weight phenol formaldehyde (LmwPF) resin having molecular weight of 600 and 45% solids contents was used as treating solution. The resin was specially synthesised and supplied by Malayan Adhesives Chemical, Shah Alam. Prior to impregnation process, two different treating solutions were prepared, i.e. 30% LmwPF resin (denoted as PF-treated) and 30% LmwPF resin incorporated with 30% urea based on solid PF (PFU-treated).

Fabrication of *compreg*-laminated wood

The pre-weighed strips were evacuated in impregnation cylinder at 85 kPa for 15 min before the treating solution was introduced separately into the chamber. The samples were left immersed in the solution under pressure of 689 kPa for 30 min. After impregnation, the treated samples were partially cured in a forced-circulation oven at 65 °C for 6 hours. After partially curing, treated strips were assembled parallel to each other to form three-layer laminae followed by pressing in hot press at 150 °C for 20 min to achieve a final thickness of 12 mm or 80% compression ratio. After compressing, the samples were conditioned in a conditioning room at 25 ± 2 °C and 65 ± 2% relative humidity until constant weight. Untreated wood with a thickness of 12 mm was used for comparison purposes.

Accelerated and outdoor ageing treatment

Accelerated ageing treatment was carried out using cyclic boil–dry treatment following River (1994) with slight modifications in the duration of submersion in boiling water and duration of drying. Due to differences in the dimensions of samples, the submersion and drying duration were modified according to Paridah et al. (2012). A total of 120 samples, treated with and without addition of urea, were soaked separately in a water bath at 100 °C for 10 min and subsequently dried in a force-circulation oven for 225 min at 107 °C. The treatments were performed for 0, 1, 2, 5 and 10 cycles. The weight and dimension of the specimens before and after treatment were recorded to analyse the loss of polymer from the specimens. The outdoor ageing test was performed according to Paridah et al. (2012). Samples were placed on racks inclined at 45° and exposed fully to tropical weathering. At the end of 1, 3 and 6 months, the samples were collected from the racks and conditioned until constant weight.

Evaluation of sample properties

The changes in mass and density of samples before and after each cycle of ageing test were determined. Weight loss of the samples was expressed in percentage using the following equation:

$$\text{Weight loss (\%)} = [(W_i - W_f)/W_i] \times 100$$

where W_i and W_f = conditioned weight of test samples before and after ageing test (g) respectively. Dimensional stability attributes, thickness swelling and water absorption were determined using vacuum soaking method in distilled water for 24 hours (Zaidon et al 1990). Oven-dried specimens (20 mm × 20 mm × 20 mm), which were cut from exposed samples, were immersed in distilled water in a beaker. The beaker filled with specimens was first vacuumed for 15 min and left to soak at atmospheric pressure. After 24 hours, the weight, thickness and volume of the samples were recorded. The MOR and modulus of elasticity (MOE) in static bending (150 mm × 20 mm × 12 mm) and block shear strength (20 mm × 20 mm × 12 mm) to test the bonding joint of the laminae were determined in accordance with BS 373: 1957 (BS 1957) with modification of sample size.

Formaldehyde emission test

Formaldehyde emission test was carried out following the method specified in the MS 1787: Part 15 (MS 2005). About 8–10 test pieces (total surface area of 1800 cm^{-2}) were placed in a desiccator above a plastic container filled with 300 mL of distilled water. They were left in the laboratory at ambient temperature for 24 hours. Formaldehyde absorbance was measured photometrically at wavelength 412 nm, and the value was used to determine formaldehyde emission using the equation below:

$$G = f \times (A_d - A_b) \times 1800/S$$

where G = concentration of formaldehyde released from the test pieces (mg L^{-1}), A_d = absorbance of the solution from the desiccators containing the test pieces, A_b = absorbance of the background formaldehyde solution, f = slope of the calibration curve for standard formaldehyde solution (mg L^{-1}) and S = surface area of the test pieces (cm^{-2}).

Data analysis

Statistical analysis was carried out using a two-way analysis of variance (ANOVA) to analyse any changes in the property values between treatment combinations. The mean was separated using Tukey's honestly significant difference (HSD) test at $p \leq 0.05$. Pearson's correlation coefficient tests were carried out to determine the correlations between dependent and independent variables.

RESULTS AND DISCUSSION

Weight loss and density changes after ageing

Density and weight of the aged samples decreased with treatment cycles and exposure durations (Figures 1 and 2). Weight loss in untreated samples was higher than in *compreg*-laminated wood where 12.0% weight loss was recorded after 6 months of outdoor exposure and 10.8% weight loss after 10 cycles of cyclic boil–dry treatment. PF-treated samples experienced the lowest weight loss between all aged samples. Similar pattern was also observed in density of the aged samples whereby decrease in density was directly affected by weight loss of samples. Untreated samples experienced the highest decrement in density (48.5 and 60.5% after accelerated and outdoor ageing respectively) in comparison with PF-treated samples (14.1 and 25.8% respectively) and PFU-treated samples (30.8 and 42.6% respectively). Loss of lignin and hemicellulose during outdoor ageing was the main factor that contributed to the reduction of density and weight (Evans et al. 1992).

Purge of low molecular weight chemical components by hot water during the boiling cycles had reduced the density and weight of the samples (Huang et al. 2014). The weight of phenolic resin-treated samples could be related to the leaching of phenol from the phenolic resin. On the other hand, both PF- and PFU-treated samples showed marked increases in densities over untreated wood suggesting that the PF resin successfully bulked the wood cell lumen and formed a highly crosslinked and hardened structure (Nabil et al. 2015). Therefore, lower weight loss was recorded in treated samples compared with untreated wood due to the low leachability behaviour of the hardened structure in the treated samples. Unlike PF-treated samples, PFU-treated samples displayed higher weight loss and density reduction. Addition of urea may increase the viscosity and molecular weight of the resin solution, resulting in poor penetration into cell wall and lumen of wood (Purba et al. 2014).

For PF-treated *compreg* laminates, the differences between weight loss after outdoor exposure for 6 months and 10 cyclic boil–dry cycles were statistically insignificant, suggesting that the two treatments were similar (Table 1). On the other hand, for PFU-treated *compreg* laminates, the differences between weight loss after 6-months outdoor exposure and 5 cyclic boil–dry cycles were statistically insignificant. Instead the 10 cycles of cyclic boil–dry treatment were more severe than 6 months exposure for PFU-treated *compreg* laminates. This indicated that addition of urea into PF resin had reduced its resistance against ageing. Urea might have

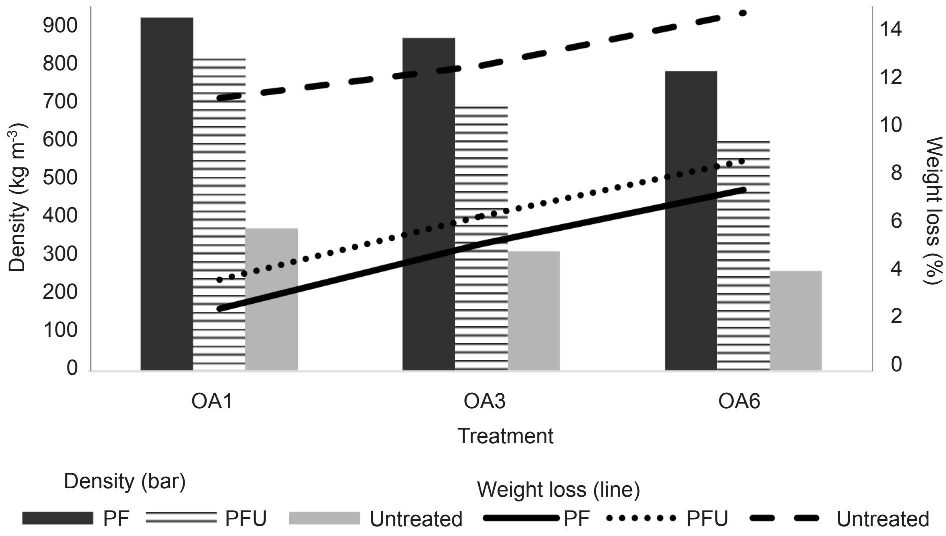

Figure 1 Weight and density changes of *compreg* laminates after outdoor ageing (OA) for 1, 3 and 6 months

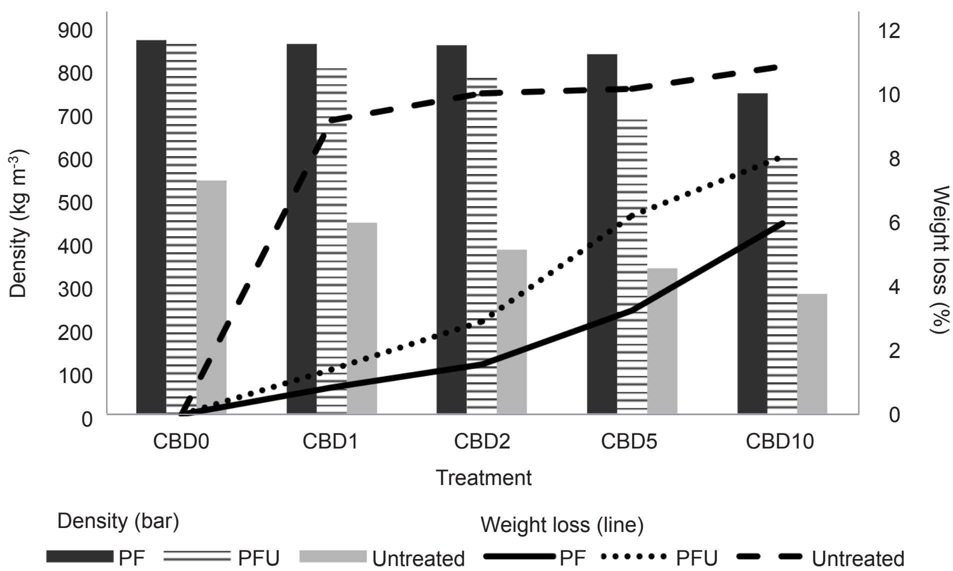

Figure 2 Weight and density changes of *compreg* laminates after 0, 1, 2, 5 and 10 cycles of cyclic boil-dry (CBD) treatment

increased the viscosity and molecular weight of the resin solution and hindered its penetration into the wood cell wall. Urea can accelerate the curing rate of PF resin and consequently lead to lower crosslinking and looser final hardened network (Zhao et al. 1999). Therefore, higher leaching rate occurred in the PFU-treated samples which led to higher weight loss. Samples exposed to outdoor ageing for 3 months were not significantly different from samples that underwent 5 cycles of cyclic boil–dry treatment. Outdoor exposure of 6 months caused higher weight loss in untreated samples compared with 10 cycles of cyclic boil–dry treatment.

Physical properties

Compreg laminates produced from sesenduk wood treated using PF solely had superior dimensional stability from those treated with admixture of PF and urea (Table 2). The findings are in agreement with Osman et al. (2005) who reported that the addition of urea into PF resin led to poor water resistance of

Table 1 Tukey's honestly significant difference between means of weight loss of *compreg* laminates after accelerated and outdoor ageing

Ageing treatment	Weight loss		
	PF-treated	PFU-treated	Untreated
OA1	c	c	b
OA3	e	d	bc
OA6	f	e	d
CBD0	a	a	a
CBD1	b	b	b
CBD2	c	c	bc
CBD5	d	e	bc
CBD10	f	f	cd

Within the same column, treatment with different letters are significantly different at $p \leq 0.05$; OA = outdoor ageing for 1, 3 and 6 months, CBD = 0, 1, 2, 5 and 10 cycles of cyclic boil–dry treatment, PF = phenol formaldehyde, PFU = phenol formaldehyde urea

Table 2 Physical properties of samples after cyclic boil–dry treatment and outdoor ageing

Treatment	WA (%)	Increment (%)	TS (%)	Increment (%)	ASE (%)	Increment (%)
			PF-treated			
CBD0	2.99 ± 1.07 a		0.50 ± 0.27 a		97.15 ± 1.53 a	
CBD1	10.81 ± 1.13 cd	261.4	0.61 ± 0.27 a	22.4	94.63 ± 0.79 ab	-2.6
CBD2	11.67 ± 1.23 de	290.1	0.68 ± 0.42 a	38.3	93.46 ± 2.10 bc	-3.8
CBD5	13.20 ± 0.85 de	341.0	0.95 ± 0.68 ab	91.4	89.96 ± 1.06 cde	-7.4
CBD10	14.24 ± 1.78 e	375.8	2.42 ± 0.38 c	389.7	87.93 ± 3.37 e	-9.5
OA1	7.99 ± 0.98 b	167.1	1.09 ± 0.42 ab	120.7	92.18 ± 1.28 bcd	-5.1
OA3	8.66 ± 1.00 bc	189.5	2.07 ± 1.19 bc	317.2	88.67 ± 2.10 de	-8.7
OA6	13.25 ± 2.46 de	343.0	4.30 ± 1.25 d	768.0	87.19 ± 2.32 e	-10.3
			PFU-treated			
CBD0	4.07 ± 0.68 a		0.73 ± 0.33 a		86.07 ± 1.43 bc	
CBD1	15.45 ± 1.90 bc	280.0	1.12 ± 0.56 ab	53.8	83.51 ± 1.86c d	-3.9
CBD2	16.72 ± 1.75 bc	311.1	2.57 ± 1.25 bc	251.3	81.06 ± 2.27 d	-7.0
CBD5	18.86 ± 1.19 c	363.7	3.55 ± 1.03 cd	385.4	92.16 ± 1.53 a	-10.7
CBD10	20.34 ± 1.15 cd	400.0	3.68 ± 0.94 cd	404.3	88.55 ± 1.08 ab	-11.6
OA1	11.17 ± 1.62 ab	174.8	1.70 ± 0.76 ab	133.4	85.71 ± 3.50 bc	-6.6
OA3	16.27 ± 1.79 bc	300.1	2.46 ± 0.78 abc	236.5	82.27 ± 2.94 cd	-9.4
OA6	26.60 ± 10.25 d	554.0	4.46 ± 1.61 d	510.4	81.49 ± 2.19 d	-12.1
			Untreated			
CBD0	61.08 ± 4.61 a		7.76 ± 1.89 a			
CBD1	70.05 ± 1.56 b	14.7	11.17 ± 0.53 b	43.9		
CBD2	77.99 ± 1.45 c	27.7	12.33 ± 0.31 b	58.9		
CBD5	103.24 ± 1.92 d	69.0	14.72 ± 1.34 c	89.7		
CBD10	110.82 ± 2.85 e	81.4	17.03 ± 0.20 d	119.5		
OA1	71.01 ± 6.53 b	16.3	10.59 ± 0.96 b	36.5		
OA3	107.71 ± 2.96 de	76.3	15.10 ± 0.33 c	94.6		
OA6	120.98 ± 1.69f	98.1	17.15 ± 0.82 d	121.0		

Values are means ± standard deviations, means of the samples treated with different treating solutions followed with the same letters are not significantly different at $p \leq 0.05$; WA = water absorption, TS = thickness swelling, ASE = anti-swelling efficiency, OA = outdoor ageing for 1, 3 and 6 months, CBD = cyclic boil–dry treatment of 0, 1, 2, 5 and 10 cycles panels. Before ageing, water absorbance values for PF- and PFU-treated samples were 3.0 and 4.0% respectively. Thickness swelling values were 0.5 and 0.7% for PF- and PFU-treated samples respectively. Untreated sesenduk exhibited the lowest dimensional stability with 61.1 and 7.8% water absorbance and thickness swelling respectively. When PF polymer bulked the wood cell wall and lumen, available void spaces decreased and subsequently led to lower water absorption capacity of the samples (Nabil et al. 2015). This was supported by the high anti-swelling efficiency values (97.2 and 86.1% for PF- and PFU-treated samples respectively). For water absorbance, in the first month of outdoor exposure, treated samples absorbed 8.0 and 11.2% water for PF- and PFU-treated samples respectively whereas the untreated wood gained 71.0% water. The samples continued to gain water at slower rates in the subsequent months. Similar behaviour was also observed for samples that have undergone cyclic boil–dry treatment. After the ageing tests, increment in thickness swelling for PF-treated and PFU-treated samples were four- to seven-fold respectively from their initial values, compared with only one-fold increase for untreated samples. The high increment in thickness swelling can be explained by first, the high initial thickness swelling values of untreated samples and second, the spring back phenomenon of compressed samples upon exposure to high humidity (Purba et al. 2014). In repeated moistening and drying cycles, any stress built into the panel during manufacturing are released.

Mechanical properties

Mechanical properties of the aged samples are summarised in Table 3. Phenolic resin treatment had imparted better mechanical properties to the *compreg* laminates in comparison with untreated sesenduk wood. The initial MOR, MOE and bending shear values of the samples before ageing are given in Table 3. Nevertheless, MOR values of the samples decreased rapidly after 6 months of outdoor exposure and only 57.9, 62.6 and 41.6% of their initial MOR values were retained for PF-treated, PFU-treated and untreated samples respectively. Most of the samples lost 8.3 to 22.4% of initial MOR after 1 month of outdoor exposure and the rate of reduction was accelerated with progressing exposure time. A similar pattern was observed for accelerated test as the PF-treated samples retained only 61.7% of their initial MOR after 10 cycles of cyclic boil treatment while the PFU-treated samples retained only 57.9%. The reduction pattern of MOE was similar to that of MOR as retention of only 35.4% was recorded in the untreated samples after 6-months outdoor exposure. Nevertheless, under the same exposure duration, PF-treated samples retained 70.1% of their initial MOE whereas PFU-treated samples only recorded a 56.0% of MOE retention. Accelerated aged samples, with exception of PFU-treated samples, retained higher percentages of both initial MOR and MOE after 10 cycles of cyclic boil–dry treatment than that of samples exposed outdoors for 6 months. This showed that outdoor ageing was more severe than accelerated ageing. Inconsistent relationship between number of cycles and exposure duration was observed based on the Tukey's HSD (Table 3). MOR values of PF-treated samples exposed outdoors for 6 months were more or less equivalent to samples treated with 10 cycles of cyclic boil–dry treatment while for PFU-treated samples, ageing for 6 months produced the same value as 5 cycles of cyclic boil–dry treatment.

For MOE, 6-month outdoor exposure revealed more severe effect compared with 10 cycles of cyclic boil–dry treatment. On the other hand, 3-months outdoor exposure equalled 10 cyclic boil–dry treatment for untreated samples. These findings suggested that outdoor ageing was more severe in comparison with accelerated ageing. However, phenolic resin treatment had somehow improved their resistance against weathering. Bending shear strength of all samples ranged from 2.2 to 4.4 N mm^{-2}. Unlike MOR and MOE, cyclic boil–dry treatment exerted greater detrimental effect on bending shear strength of samples compared with outdoor ageing where 10 cycles of boil–dry treatment was greater than 6 months of outdoor ageing. Bending shear strength was highly dependent on bonding between PF resin and wood fibre. Boiling cycle in accelerated ageing test had degraded the glue line and/or wood substance and led to reduction in bending shear strength (Hayashi et al. 1990).

Correlation between outdoor ageing and accelerated ageing test

Not all possible relationships between outdoor ageing, accelerated ageing and test variables of

Table 3 Mechanical properties of samples after cyclic boil–dry treatment and outdoor ageing

Treatment	MOR (N mm^{-2})	Retention (%)	MOE (N mm^{-2})	Retention (%)	Shear (N mm^{-2})	Retention (%)
			PF-treated			
CBD0	133.92 ± 5.32 a		10125 ± 648 a		4.38 ± 0.19 a	
CBD1	122.41 ± 3.44 b	91.4	9661 ± 743 ab	95.4	4.18 ± 0.19 ab	95.5
CBD2	113.61 ± 4.70 bc	84.8	8824 ± 514 bc	87.2	3.91 ± 0.08 bc	89.4
CBD5	92.06 ± 4.66 d	68.7	8494 ± 525 bc	83.9	3.25 ± 0.08 de	74.2
CBD10	82.61 ± 4.75 e	61.7	7801 ± 1056 cd	77.1	2.65 ± 0.11 f	60.7
OA1	115.05 ± 3.11 bc	85.9	9225 ± 494 b	91.1	3.65 ± 0.32 cd	83.3
OA3	107.75 ± 3.88 c	80.5	8462 ± 895 bc	83.6	3.26 ± 0.14 de	74.6
OA6	76.26 ± 7.24 e	56.9	7095 ± 686 d	70.1	3.05 ± 0.12 ef	69.7
			PFU-treated			
CBD0	110.95 ± 4.74 a		9682 ± 293 a		3.54 ± 0.16 a	
CBD1	91.14 ± 6.26 b	82.2	8353 ± 802 b	86.3	3.21 ± 0.07 ab	90.7
CBD2	84.49 ± 3.70b c	76.2	7172 ± 505 cd	74.1	2.98 ± 0.10 b	84.1
CBD5	70.17 ± 4.34d e	63.2	6564 ± 820 de	67.8	2.44 ± 0.14 d	68.8
CBD10	64.23 ± 6.69 e	57.9	5966 ± 743 ef	61.6	2.17 ± 0.33 d	61.1
OA1	101.73 ± 6.19 a	91.7	8225 ± 655 bc	85.0	3.19 ± 0.19 ab	90.1
OA3	78.21 ± 5.17 cd	70.5	7033 ± 458 bcd	72.7	2.85 ± 0.15 bc	80.5
OA6	69.45 ± 4.28 de	62.6	5422 ± 411 f	56.0	2.47 ± 0.08 cd	69.6
			Untreated			
CBD0	72.63 ± 0.87 a		3387 ± 172 a			
CBD1	59.35 ± 0.64 b	81.7	2873 ± 73 b	84.8		
CBD2	52.62 ± 2.62 c	72.4	2138 ± 145 c	63.1		
CBD5	42.54 ± 1.10 d	58.6	1657 ± 109 d	48.9		
CBD10	40.95 ± 3.90 d	56.4	1650 ± 52 d	48.7		
OA1	56.39 ± 2.58 bc	77.6	2210 ± 48 b	65.2		
OA3	39.94 ± 5.44 d	55.0	1607 ± 98 d	47.4		
OA6	30.24 ± 1.63 e	41.6	1198 ± 102 e	35.4		

Values are means ± standard deviations, means of the samples treated with different treating solutions followed with the same letters are not significantly different at $p \leq 0.05$; MOR = modulus of rupture, MOE = modulus of elasticity, OA = outdoor ageing for 1, 3 and 6 months, CBD = cyclic boil–dry treatment of 0, 1, 2, 5 and 10 cycles

this study were explored. Pearson's correlation test was performed and some good correlations (r = 0.71 to 0.99) were found for MOR and MOE between cyclic boil–dry treatment and outdoor ageing for PF-treated and PFU-treated *compreg* laminates. However, poor correlations were found between cyclic boil–dry treatment and outdoor ageing for untreated samples. Good correlations were also observed for water absorbance and thickness swelling between cyclic boil–dry treatment and outdoor ageing for PF-treated *compreg* laminates and untreated sesenduk wood. For PFU-treated samples, weak correlations (r = 0.55 to 0.69) were observed for water absorbance after 1-month outdoor exposure and after 1, 2, 5 and 10 boil–dry cycles. Nevertheless, the relationship became stronger (r = 0.95 to 0.97) as the outdoor exposure time increased from 1 to 6 months. Although the results implied that the properties of some samples after 1 boil–dry cycle would consistently correlate with properties after 1, 3 and 6 months of outdoor ageing, some samples, however, failed to establish good relationship. Therefore, extended outdoor exposure time and cyclic boil–dry cycles are needed. River (1994) found that the strongest correlation was obtained between MOR after 5 boil–dry cycles and MOR, after 1 year of outdoor ageing. Thus, since outdoor exposure is more severe than accelerated ageing, extending the cyclic boil–dry treatment to 15 cycles may facilitate the establishment of stronger correlation between accelerated and outdoor ageing tests.

Formaldehyde emission

Formaldehyde emission from PF-treated *compreg*-laminated wood was greatly reduced by incorporation of 30% urea into PF resin, i.e. from 5.87 to 0.18 mg L^{-1} (Figures 3 and 4). The findings were in agreement with Zaidon et al. (2015c) who found that the formaldehyde emission of *compreg* wood reduced by 77.4 to 96.4% after addition of urea. Free formaldehyde emission in the PF resin is absorbed by urea and formed crosslinked urea-formaldehyde polymer which causes lower emission of formaldehyde (Rabi'atol-Adawiah et al. 2012). Formaldehyde emission of the *compreg*-laminated wood decreased with exposure times and boil–dry cycles. Formaldehyde decreases with time and the reduction is linear with the progression of time (Zinn et al. 1990).

CONCLUSIONS

The study revealed that PF- and PFU-treated *compreg* laminates showed significant reduction in properties after subjected to either outdoor ageing or accelerated ageing test. Aged samples experienced weight and density loss after cyclic boil–dry cycles and outdoor exposure. Untreated samples lost the highest density after accelerated and outdoor ageing (48.5 and 60.5% respectively). PF-treated samples lost

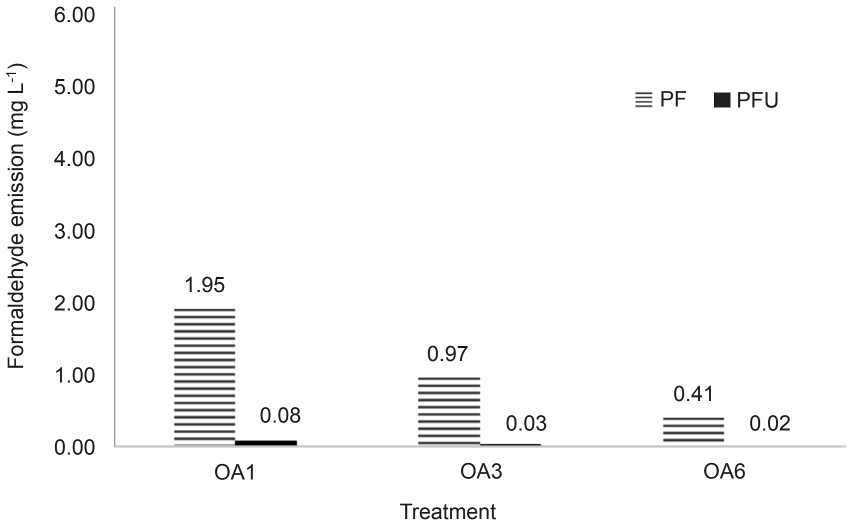

Figure 3 Formaldehyde emission of *compreg*-laminated wood after outdoor ageing (OA) for 1, 3 and 6 months

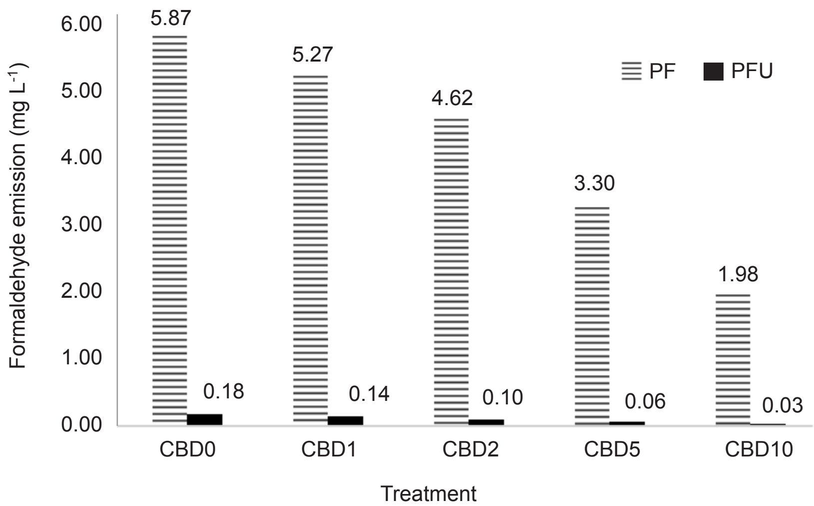

Figure 4 Formaldehyde emission of *compreg*-laminated wood after 0, 1, 2, 5 and 10 cycles of cyclic boil–dry (CBD) treatment

only 14.1 and 25.8% of its density respectively while PFU-treated samples lost 30.8 and 42.6% respectively. Generally, all properties decreased as the number of boil–dry cycle and duration of outdoor exposure increased. Water absorption of PF-treated samples exhibited marked increases from 3.0 to 14.2 and 13.3% after accelerated and outdoor ageing respectively. Higher water absorption was recorded in the aged PFU-treated samples. Thickness swelling of the aged samples displayed similar pattern as that of water absorption. Reduction in strength of both PF- and PFU-treated samples was observed as most of the aged samples retained only 56.9 to 62.6% of its initial MOR. PFU-treated samples lost 44.0% of MOE after 6-months of outdoor ageing. Formaldehyde emission of the *compreg*-laminated wood decreased with exposure times and boil–dry cycles. Addition of urea into PF resin reduced formaldehyde emission of the samples from 5.87 to 0.18 mg L^{-1}. Good correlations were observed between accelerated ageing and outdoor ageing (r = 0.71–0.99). However, there was slight difference in outdoor ageing and accelerated ageing tests in terms of mechanical and physical properties. Outdoor ageing yielded higher reduction of mechanical and physical properties of the samples, suggesting that outdoor exposure was more severe than cyclic boil–dry treatment. Similar trend was also observed for formaldehyde emitted from treated samples. Therefore, higher number of boil–dry cycles might be needed to establish a stronger correlation between the two ageing tests.

ACKNOWLEDGMENT

This work was supported by the Inisiatif Putra Berkumpulan grant (No. 9413403) from the Universiti Putra Malaysia.

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